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Abstract

Background

Diets reduced or low in carbohydrates are becoming increasingly popular. The replacing foods and their accompanying nutrients determine the health effects of such diets. However, little is known about the dietary intake of people consuming reduced or low carbohydrate diets.

Method

In this cross-sectional study, the dietary and nutrient intake of individuals aged 16-75 years consuming fewer than 40% of kcal from carbohydrate (n=430) was compared to individuals consuming equal or more than 40% kcal from carbohydrate (n=1833) using the UK National Diet and Nutrition Survey.

Results

Those consuming fewer than 40% of total kcal from carbohydrate reported higher consumption of red and processed meat, butter, oily fish and vegetables, and lower consumption of soft drinks and pulses than those with a normal carbohydrate intake. After adjusting for socioeconomic status only red meat intake was different between the groups, and reached the maximum daily intake recommended by health bodies. There were no significant differences in micronutrient intakes between the groups, but magnesium, selenium, potassium along with fibre were lower than recommended amounts across the cohort.

Conclusions

Individuals consuming reduced or low carbohydrate diets could benefit from replacing some red meats with white meats and vegetable sources of protein, and increasing vegetable intake.

Background

There has been widespread interest in low- or reduced carbohydrate (CHO) diets in the popular media⁽¹⁾ and increasingly within clinical research^(2,3). Terms such as low- or reduced CHO diets are limited as CHOs are a heterogeneous group of compounds, and the quality of CHO largely determines its metabolic effects^(4,5). Nevertheless, the majority of CHO consumed in most parts of the world is rapidly available starch^(4,6), and there is accumulating data suggesting that limiting its consumption aids with weight loss, at least short-term^(2,3,7) and may have some favourable metabolic effects, including decreased triglycerides and glucose concentrations, and increased HDL-cholesterol (HDL-C)^(2,7). Nevertheless, some concerns about their long-term safety remain^(7,8).

In reduced- or low-CHO diets, the CHO may be replaced by some protein but usually fat^(2,3,7). The replacing macronutrient or food may augment, or attenuate the beneficial effect of reducing carbohydrate on metabolic risk factors. For example, replacement of CHOs such as white rice or bread with fish, nuts or olive oil lowers LDL-cholesterol (LDL-C) and fasting triglycerides^(9,10), whereas replacement with foods high in saturated fat such as butter, red meat or cream can increase LDL-C⁽¹¹⁾. Furthermore, consumption of foods high in saturated fat can lead to increases in visceral and liver fat, and decreases in insulin sensitivity even in the context of a very-low carbohydrate (ketogenic) diet; whereas foods high in unsaturated fat such as olive or vegetable oils have a neutral or beneficial effect on these important risk factors⁽¹²⁻¹⁴⁾.

In addition, other nutritive and non-nutritive components of the replacing foods may be as, or more important than the fatty acid composition. For example, the presence of nitrates and haem iron⁽¹⁵⁾ in red meat may explain the association between their consumption and increased risk of colon cancer⁽¹⁶⁾. Similarly, the sodium and nitrate content of processed red meats may explain the relationship with increased risk of cardiovascular disease (CVD)⁽¹⁷⁾. Conversely, the presence of micronutrients and non-nutritive compounds such as polyphenols may at least partly mediate the beneficial effects of nuts and extra-virgin olive oil on multiple aspects of human health⁽¹⁸⁾.

Despite the importance of the replacing food to health and well-being, little is known about the types of foods consumed by individuals restricting dietary CHOs outside of clinical research. An online non-validated survey of people following a low-CHO diet⁽¹⁹⁾ found that more than half of respondents reported increasing their intake of salad and greens, but did not

measure absolute intake, micronutrient composition of the diet or other dietary factors. This analysis therefore aims to determine the dietary and nutrient intake of individuals consuming fewer than 40% of kcal from CHO.

Methods

This is a cross-sectional study comparing dietary intake in individuals with a reduced carbohydrate diet (RCHO), with those with a normal intake (NCHO) in the National Diet and Nutrition Survey (NDNS) ⁽²⁰⁾. The 40% cut off was chosen as this is below the current and previous recommendations of 50% and 47% of total energy from CHOs by the 2015 Scientific Advisory Committee on Nutrition's report on Carbohydrates and Health and Committee on the Medical Aspects of Food Policy report, respectively ⁽²¹⁾. It is also the proportion of kcal from carbohydrate used in a recent report on dietary treatment of obesity of a "moderate low-CHO diet" ⁽²²⁾.

National Diet and Nutrition Survey

Subjects and Study Design

The NDNS is a national dietary survey carried out every 1.5 years across the United Kingdom. Full details of the methodology can be found in Chapter 2 of the full report ⁽²⁰⁾. In brief, a sample of people representative of the UK population was drawn from the Postcode Address File (PAF), a list of all the addresses in the UK. Information about the survey was posted to all selected addresses followed by a face-to-face visit by an interviewer to recruit participants in the eligible age range. From each household the interviewer randomly selected up to one adult and one child to take part. For this study, only ages 16-75 years were included. Other groups excluded included women who were pregnant or breastfeeding. This report presents combined results from Years 1, 2, 3 and 4 of the NDNS (2008/09 – 2011/12. Ethical approval for the study was obtained from the Oxfordshire A Research Ethics Committee. Research governance approval was sought for all participating NHS laboratories and obtained where required by each Research and Development Committee ⁽²⁰⁾.

Dietary Data

Participants were provided with a diary and asked to keep a record of everything they ate and drank in and outside the home over four days including both weekend days ⁽²⁰⁾. To ensure compliance, interviewers contacted the participants on the second or third day of data collection in person or over the telephone, to provide encouragement and to collect any missing detail for foods ⁽²⁰⁾. Portion sizes were estimated using household measures and weights from labels. The diaries included photographs of ten frequently consumed foods and pictures of life-size spoons and a life-size glass to aid accurate recording ⁽²⁰⁾. If participants did not know what type of food they had consumed, default foods were used; for example, for milk this was semi-skimmed, for fat spread this was reduced fat spread (not polyunsaturated). This method is described in detail elsewhere ^(20,23).

Response Rates

46% of the 21,573 addresses issued to interviewers were eligible for selection of which 9% refused before the household selection could be carried out. Of 9,858 eligible households, 56% of selected participants completed three or four dietary recording days in Year 1, 57% in Year 2, 53% in Year 3 and 55% in Year 4. Including only those aged 16-75 years of age left 2263 participants.

Socioeconomic Status

The NDNS dataset includes the Index of Multiple Deprivation (IMD), which is separated into quintiles. The IMD data is only available for England. Therefore, in this study, adjustment for socioeconomic status (SES) was carried out for the 1885 individuals residing in England.

Dietary Analysis

Food and nutrient intakes were calculated using DINO (Diet In Nutrients Out), a dietary assessment system developed at the Human Nutrition Research Centre at Cambridge University ⁽²³⁾. The databank is based on McCance and Widdowson's Composition of Foods series ⁽²⁴⁾, Food Standards Agency Food Portion Sizes ⁽²⁵⁾, and manufacturers data where applicable. The database is also updated every year by the Food Standards Agency including

the creation of new food codes for novel or fortified food products, updates to existing food codes relating to manufacturer reformulation and removal of foods which are no longer sold.

Food consumption and nutrient intake were analysed by sex and age group (11-18 years and 19-64 years) in order to provide percentages of reference nutrient intakes. The data were weighted to account for non-response bias and bias due to differences in the probability of households and individuals being selected to take part^(20,23). This was done by correcting for socio-demographic differences between the composition of the NDNS sample the entire UK population.

Statistical Analysis

The independent variable was created by splitting the dataset into those with a percentage of total kcal of CHO fewer than or equal to/more than 40%. For normally distributed dependent variables, independent t-tests were used. The Mann-Whitney U test was used to examine differences in median intake for non-parametric variables such as particular foods and food groups. Where there were ties in the data, the asymptomatic p value is reported. Proportions between groups were compared using χ^2 tests. ANCOVAs were used to assess differences in foods and food groups with SES as a covariate, for which the dependent variable was log-transformed, and histogram plots used to check for normal distribution of residuals. The NDNS dataset provides information on whether individuals were following a particular diet, including vegetarian, vegan, diets for weight reduction and gain; cholesterol reducing diets; low allergy and others. These individuals were included but sensitivity analyses conducted with (n=2263) and without (n=2159) their data. Data analysis was carried out using SPSS for Windows (IBM SPSS Statistics Version 23) and a significance level of $P < 0.0001$ was used throughout to take into account multiple testing of dependent variables.

Results

Participants

Baseline characteristics are shown in table 1. Dietary data was provided by 2263 individuals, of whom 430 (20%) had a reported CHO intake of fewer than 40% of total kcal (RCHO) and 1833 (80%) reported equal or more than 40% of total kcal from CHO (NCHO). Less than half the NDNS sample agreed to provide biochemical data. Exact numbers for whom biochemical and anthropometric data are available are shown in Table 1. The NCHO group were significantly younger and had a higher BMI and fasting plasma glucose compared to the RCHO group ($P<0.0001$ for all comparisons). There were no differences in SES ($P=0.12$).

Consumption of Foods

People in the RCHO group reported a higher consumption of red meat, processed meat and butter, but also reported a higher consumption of vegetables and oily fish (Table 2). The RCHO group also reported a lower intake of soft drinks (not low-calorie versions) and pulses. ($P<0.0001$ for all comparisons). After adjusting for multiple comparisons there were no differences in reported intakes of other foods or food groups. There were no differences in the proportion of individuals consuming 5 or more fruits and vegetables per day (RCHO: 27% vs NCHO: 30%, $P=0.102$).

Intake of Macro and Micronutrients

As expected, people in the RCHO group reported a higher percentage of kcal from protein, total fat and each fat class ($P<0.0001$ for all comparisons)(Table 3). The RCHO group consumed less dietary fibre than the NCHO group, but both were under current recommendations. Non-milk extrinsic sugar (NMES) consumption was higher in both groups than current (2015) recommendations ⁽²¹⁾, but the RCHO group were within previous recommendations for NMES ($<10\%$ kcal) in contrast to the NCHO group.

After controlling for multiple comparisons, there were no differences in intakes of micronutrients between the RCHO and NCHO diets. Consumption of magnesium, potassium, and selenium were below current RNI for both groups (Figure 1).

Adjustment for Socioeconomic Status

After adjusting for SES only the difference in red meat intake between groups remained significant ($P=0.003$). The differences in vegetable intake was explained entirely by SES.

Sensitivity Analysis

The results were not different when excluding individuals on restrictive diets.

Discussion

In this cross-sectional study, individuals consuming fewer than 40% of total kcal from CHO (reduced carbohydrate:RCHO) consume more red meat, processed meat, butter, oily fish and vegetables, but fewer soft drinks and pulses than those with a normal ($<40\%$ of total kcal) carbohydrate (NCHO) intake. After adjusting for SES, only red meat remained significantly different. There were no significant differences in white meat, total fibre, nuts and seeds or total fruit intake between the groups.

A widespread concern regarding low-CHO diets is that replacement of CHO with foods high in saturated fat may raise LDL-C ^(8,11,26). In this study, the percentage of kcal from saturated fat was significantly higher in the RCHO group. The most likely explanation for the increase or lack of LDL-C reduction despite significant weight loss observed in low-CHO clinical studies is due to increased intake of foods such as butter and red meat. However, interpretation of low-CHO clinical studies is challenging because many do not report detailed food intake. Furthermore, a 28-day randomised control trial comparing red-meat versus white-meat in the context of a very low-CHO diet ($<20\%$ kcal from CHO) found no differences in LDL-C between the groups ⁽²⁷⁾. It is also worth mentioning that attenuation of or increases in total LDL-C may be offset by favourable alterations in cholesterol fractions, alongside increases in HDL-cholesterol and reductions in triglycerides when refined CHO is replaced with foods high in saturated fat ^(28,29).

In addition to a significantly higher consumption of red meat, individuals consuming a RCHO diet also reported significantly higher intake of processed meats such as bacon and ham. The presence of compounds such as nitrites, advanced glycation end-products and aromatic hydrocarbons ⁽²⁹⁾ in red and processed meat products have been linked to type 2

diabetes and some cancers, and illustrate the importance of consideration of foods beyond their effects on the lipid profile ^(5,6,30,31). Therefore, while red meat such as beef provide nutrients commonly lacking in the UK diet such as iron, zinc and selenium, its overconsumption, particularly when processed should be discouraged. The UK government recommends people who regularly consume >90g/day of red meat should cut down to 70g/day ⁽³²⁾. In this study, the median intake of red meat was 91g/day in the RCHO group, suggesting that these individuals could benefit from replacing some red meat with white such as chicken or fish.

In contrast to the relative controversy of replacing refined CHO with saturated fat, replacement of refined CHO with foods high in monounsaturated fats such as olive oil and avocado, or polyunsaturated fats including sunflower oil, nuts and oily fish has neutral or beneficial effects on a multitude of health factors ⁽³³⁻³⁵⁾. Again, in addition to the fatty acid profile of these foods, nutritive and non-nutritive components such as polyphenols are also likely to be as important ^(18,36). In the current study reported intakes of total oils, including oils high in unsaturated fats such as sunflower and olive oil was relatively low (and lower than butter for both groups). This supports previous reports of low consumption of olive oil in the UK which was 16.0ml per week in 2013 ⁽³⁷⁾. Individuals choosing to minimise dietary CHOs may benefit from replacement of some butter with a variety of unsaturated oils.

Other concerns expressed about the long-term health effects of low-CHO diets include the lack of essential nutrients ⁽³⁸⁾. In this study, the RCHO group had a higher percentage RNI of most micronutrients apart from vitamin C than the NCHO group, but no differences were significant. Magnesium, potassium and selenium were lacking in both groups and may reflect the low intake of fruits, vegetables, seeds and nuts across the cohort. However, the RNIs for these minerals are also based on limited data ⁽²⁰⁾, and thus should be taken with caution. It's worth again noting that the micronutrient content of the diet represents one aspect of nutrition, and non-nutrient components of a variety of foods are also vital to health ^(18-21,36).

The benefits of consuming a variety of high-fibre foods are well documented ⁽³⁹⁾, and concerns have been raised that low or reduced CHO diets may be deficient in fibre ⁽²⁾. In this study, both groups consumed lower than recommended amounts of fibre, even without considering the recent increase in the dietary reference value to 30g/day using the Association of Official Analytical Chemists (AOAC) method ⁽²¹⁾. In the UK, the major sources of dietary fibre are breads, cereals and vegetables ⁽⁴⁰⁾ while per portion size, legumes,

some fruits such as raspberries, apples and pears; vegetables such as artichokes, peas and broccoli and high-bran cereals provide the most fibre in the diet ⁽²³⁾. Fewer than 30% of either group reported a consumption of 5 or more fruits or vegetables per day, and white bread, pasta, rice and potatoes were the largest contributors to the CHO content of both diets. It is also worth noting that recent high-profile studies examining the Mediterranean diet pattern also included more fibre than currently consumed in Western diets ^(3,41) and a very high fibre (28g/1000 kcal) diet has been shown to improve glucose homeostasis compared to a low-CHO high-monounsaturated fat diet in people with type 2 diabetes ⁽⁴²⁾. Furthermore, there is some evidence to suggest that dietary fibre can offset some the increased risk of high-meat consumption on colon cancer ⁽⁴³⁾. Therefore, individuals who choose to consume a low-CHO diet should plan carefully to ensure they benefit from a range of dietary fibre from a variety of sources. This may be more important in low-income groups who consume more red meat, and fewer fruits and vegetables.

The detrimental impact of excessive non-milk extrinsic sugar (NMES) (now termed free sugar) consumption on multiple aspects of health was recognised by the 2015 SACN report which now recommends individuals aged >11 years consume no more than 5% energy from such sugars ⁽²¹⁾. In this study, both groups exceeded this recommendation, but the reported intake of NMES was significantly greater in the NCHO group, largely reflecting the differences in soft drink consumption. While the RCHO group reported a consumption of total CHOg/day which was approximately 80% of that reported in the NCHO, the reported consumption of NMESg/day was approximately 70% of that in the NCHO group. This suggests that restriction of dietary CHO is associated with a preferential reduction in free sugar intake, which will likely be beneficial for health. Future studies should examine whether further restriction of CHO leads to intakes of added sugars to levels within the current recommendations.

In this study, the RCHO group consumed more kcal from protein than the NCHO group, with a median intake of 16.8% total kcal. The long-term safety of high-protein diets has been questioned, based on the posited deleterious effect on renal function and bone density ⁽³⁸⁾. While emerging evidence suggests the effect of total protein on both bone and renal health may be overstated, this remains an understudied area ⁽⁴³⁾. Given the reported food intake in this study, it is likely the majority of protein came from animal sources, with minimal vegetable protein from foods such as pulses. Diets high in animal protein have been linked with increased risk of morbidity including inflammatory bowel disease and type 2 diabetes

^(44,45). In contrast, diets high in pulses and other sources of vegetable protein have been linked to positive health outcomes and decreased mortality ⁽⁴⁶⁾. Given the association between plant-based diets and good health, both groups in this study would benefit from increasing vegetable intake, to include where possible, vegetable sources of protein.

The RCHO had a higher BMI and fasting plasma glucose than the NCHO group. The direction of this relationship cannot be established from a cross-sectional analysis. It may be the case that the RCHO group had altered their diets to reduce their body weight. Given the rising interest in RCHO diets in the UK⁽¹⁾ this is a real possibility. On the other hand, the RCHO (which was higher in kcal) may have led to an increase in weight, alongside a slight, but significant increase in fasting glucose. While RCHO appear to be as effective as -if not superior to - NCHO diets for weight loss ^(2,3), some authors have argued that RCHO may also lead to weight gain ⁽⁴⁷⁾. The available data do not suggest that RCHO diets increase the risk of obesity ⁽⁴⁸⁾. However, given the interest in RCHO diets, the longitudinal association of RCHO diets with risk of obesity, type 2 diabetes and CVD should be further studied.

This cross-sectional analysis has some strengths including a large sample size, which is representative of the UK population. The collection of both nutrient and food information also allows a practical analysis of the results. Given the recent interest in LCHO diets, this in-depth analysis of food and nutrient intake, the first of its kind, may also provide some insight into typical dietary intake, and as such can help public health education efforts. However, some weaknesses must be acknowledged. Firstly, the categorization of the RCHO and NCHO diets was based on observed differences at a point in time, and may not reflect the intakes of people who deliberately choose to consume a LCHO diet. For example, the RCHO group was significantly older than the NCHO group and the differences may therefore reflect changes in dietary intake across the life course. Furthermore, differences in dietary intake from NCHO may be greater in individuals consuming a very low-CHO or ketogenic diet. Future research should explore these questions. Furthermore, as a self-reported survey, the NDNS dataset suffers from underreporting, with energy intake underreported by approximately one third in the doubly-labeled water method validation of this survey (Appendix X in ref 20). Validation studies in normal and overweight individuals suggest that fat and carbohydrate foods are particularly underreported ⁽⁴⁹⁾. While it might be suggested that underreporting would be equally distributed across the RCHO and NCHO groups, individuals aiming to reduce foods such as carbohydrates (RCHO group) may underreport these to a greater degree, as individuals may underreport food items they consider unhealthy ⁽⁴⁹⁾. Given the reported

median daily intake of absolute grams of carbohydrate was 175.7g/day (141.6-216.4), in this study, the actual intake may therefore reach ~260g/day, twice the recommended intake of a low-CHO ⁽⁵⁰⁾. The individuals included in the RCHO group in this study may therefore not represent individuals who are aiming to reduce dietary CHO. A lower cut-off to <26%kcal from CHO to define the RCHO group may have generated a group more likely to be intentionally reducing CHO intake, but would have resulted in a RCHO group of 15 subjects. Finally, in contrast to underreporting of perceived unhealthy foods, perceived healthier foods such as fruits and vegetables may be overreported ⁽⁴⁹⁾, and thus the true intake across this cohort may be even lower than presented here.

In conclusion, this study finds that people consuming fewer than 40% kcal from CHO consume more red and processed meat, oily fish, butter and vegetables, but fewer soft drinks and pulses than people consuming a normal CHO diet. After controlling for socioeconomic status, only the consumption of red meat was different between the groups.

Transparency Declaration

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained. The reporting of this work is compliant with STROBE guidelines.

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Figure 1: % of reference nutrient intake for a) vitamins and b) minerals amongst the reduced-carbohydrate and normal-carbohydrate groups. Vitamins: B1: Thiamin; B2: riboflavin; B3: niacin; B6: pyridoxine; B12: cobalamin. Minerals: Fe: Iron; Ca: Calcium; Mg: Magnesium; K: Potassium; Zn: Zinc; Cu: Copper; Se: Selenium; I: Iodine; Na: Sodium. RC: reduced carbohydrate group; NC: normal carbohydrate. Data are presented as means \pm SEM.